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Whitepaper on

Prioritising Key Sectors in the Indian Economy for Deep Electrification

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India has committed to reducing the Greenhouse Gas (GHG) emission intensity of its Gross Domestic Product (GDP) by 45 percent below 2005 levels by 2030

1. Introduction

India has committed to reducing the Greenhouse Gas (GHG) emission intensity of its Gross Domestic Product (GDP) by 45 percent below 2005 levels by 2030 at the COP 26 conference held in Glasgow[1]. It aims to achieve the net-zero target by 2070. Several econometric studies have established that energy usage by a country has a positive correlation with its Gross Domestic Product (GDP). India being a developing economy, will have to strike a balance between registering continuous GDP growth and decarbonisation of its energy and other energy-intensive sectors. This necessitates enhancing resource efficiency and exploring new clean technologies to meet future energy demand.

Electrification is emerging as a major trend to achieve deep decarbonisation in energy markets around the world[2]. It refers to the process of replacing technologies that use fossil fuels with technologies that use electricity as a source of fuel. And depending on the resources used to generate electricity, electrification can potentially reduce emissions. Therefore, if policymakers seek to decarbonise the hard-to-abate sectors, replacing fossil fuels with electricity as a fuel source may currently be one of the only technologically viable options. More importantly though, electrification of non-power sectors would consolidate carbon mitigation efforts and allow policymakers to focus on decarbonising the electrical grid. This might prove far more feasible as opposed to decarbonizing the non-power sectors separately.

As energy and electricity impact every major sector of the economy, deep electrification[3] has the potential to accelerate deep decarbonisation[4]. In addition, it opens avenues to support the circular economy, thereby improving resource efficiency and leading to new jobs emerging from a well-planned just transition process. As a first step to contextualising deep electrification strategies for critical sectors in India, it is necessary to map all the sectors in the economy and identify priority sectors among them. This paper provides a description of the methodology followed to identify and rank various sectors for deep electrification in India. The results of this exercise prompt selection of sectors to conduct a deep dive into exploring the implementation of direct and indirect electrification strategies.

Electrification refers to the process of *replacing technologies that use fossil fuels* with technologies that use electricity as a source of fuel

1 See: https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1847812.
2 See: https://www.greenbiz.com/article/we-need-clean-grid-electrification-decarbonize.
3 Deep electrification refers to the electrification of all energy consumption sectors to the maximum extent possible.
4 See: https://www.nrel.gov/docs/fy18osti/71500.pdf.

2. Literature Review

India is committed to combating climate change by effecting an energy transition based on equity and the principle of common but differentiated responsibilities and respective capabilities (CBDR&RC). Achieving a reduction in country-level emissions intensity is imperative to its strategy. However, this study acknowledges that being a developing economy India will see an increase in energy consumption, and thereby the emissions quantum may see an overall increase. Thus, the framework employed as part of this study, as well as the parameters identified towards deep electrification strategies are cognizant of India's need for socio-economic growth.

An economy-wide mapping of sectors and sub-sectors in India requires an understanding of the extent of direct and indirect electrification to be considered. Concomitantly, deep electrification strategies for specific sectors from select countries were studied. Prioritising sectors warranted quantitative and qualitative attributes to be considered to arrive at a holistic view of the need and potential for implementing deep electrification pathways.. In this regard, a Multiple-Criteria Decision-Matrix (MCDM) exercise was performed to arrive at a ranking for the sectors, and the various approaches to expediting this MCDM exercise were reviewed.

2.1. GLOBAL CASE STUDIES ON DEEP ELECTRIFICATION

2.1.1. UNITED STATES OF AMERICA (USA)

Strategy to Net-Zero

The US has pledged to reach net-zero emissions by 2050. The viable routes identified to achieve net-zero emissions across all sectors involve five key transformations:

- Decarbonisation of electricity: The transition to clean electricity systems is supported by decreasing costs of solar and wind technologies, policies at the federal and sub-national level, and rising consumer demand for clean power sources. The country has set a goal to achieve a 100 percent clean electricity system by 2035.
- Electrifying end-uses and adoption of alternate fuels: Technologies that enable electrification of cars, buildings, industrial processes, etc., with clean power sources are critical to achieving net-zero. Hard-to-abate sub-sectors such as aviation and shipping must adopt carbon-free hydrogen and sustainable biofuels.
- Improving energy efficiency: Striving to incorporate efficiency across sectoral activities and end-uses will enable the same output to be achieved with lesser energy consumption from a clean source. Approaches ranging from adoption of energy-efficient appliances to sustainable manufacturing processes will further the country's net-zero emissions goal.
- Reducing Methane and other non-CO_2 emissions: The US is a signatory to the Global Methane Pledge and has committed to reducing methane emissions by at least 30 percent by 2030. Further, the US has set a target to achieve emission levels between 91-100 percent of 1990 standards by 2050.
- Scale-up CO_2 removal: This transformation is in consideration of non-CO_2 emissions from sectors such as agriculture. Thus, mainstreaming carbon-capture technologies and expanding land-carbon sinks is critical to achieving net-zero emissions.

Additionally, the US has also laid emphasis on green hydrogen production and has set an interim target to develop 13.5 GW of electrolyzer capacity by 2030.

CASE STUDY

Electrification of Steel Industry in the US

The iron and steel industry accounts for close to 20 percent of industrial energy use and about a quarter of direct industrial CO_2 emissions in the world. Globally, over 7 percent of GHG emissions are attributed to iron and steel production. Coal is used as the primary fuel and feedstock for the chemical reduction of iron oxide. Considering the volume of steel produced, the sector stands out as one of the highest CO_2 emitting industries.

The conventional blast furnace-basic oxygen furnace (BF-BOF) employed for crude steel production constitutes the following processes – Sintering, Pelletising, Coke making, Blast furnace, and Basic oxygen furnace. The total energy required for this process is 5,482 kWh/tonne[5], of which thermal demand constituted 88.6 percent. Electrified steel production processes such as scrap-based Electric Arc Furnace (EAF), Hydrogen Direct Reduced Iron (DRI) based EAF, and steel making by electrolysis has a lower total energy requirement, with most of the energy requirement having shifted to electricity. Table 1 shows the main production processes from each of the electrified steel-making processes along with their corresponding energy requirement.

Table 1: Electrified Steel Making Processes[6]

Electric Steel-Making Process Routes	Main Production Processes	Electrical Demand (kWh/tonne)	Thermal Demand (kWh/tonne)
Scrap- EAF	1. EAF 2. Casting, rolling, and finishing	710	667
H_2 DRI-EAF	1. H_2 production 2. DRI production 3. EAF 4. Casting, rolling, and finishing	3500	667
Production by Electrolysis	1. Electrolysis of iron ore 2. Casting, rolling, and finishing	3300	556

Assuming the electricity grid is decarbonised by 2050, all the three alternate steel-making processes have significant and relatively similar CO_2 emissions reduction potential, thus aiding the attainment of net-zero emissions.

5 See: https://static1.squarespace.com/static/5877e86f9de4bb8bce72105c/t/6018bf7254023d49ce67648d/1612234656572/Electrifying+U.S.+Industry+2.1.21.pdf.

6 See: https://static1.squarespace.com/static/5877e86f9de4bb8bce72105c/t/6018bf7254023d49ce67648d/1612234656572/Electrifying+U.S.+Industry+2.1.21.pdf.

2.1.2. FRANCE

Strategy to Net-Zero

France has committed to reaching net-zero Greenhouse Gas (GHG) emissions by 2050 and has laid out a National Low Carbon Strategy in this regard. France's net-zero commitments include reduction in energy consumption by 50 percent, and making energy production carbon-free by 2050. France has also set a target to reduce non-energy emissions by 38 percent from its 2015 levels in the farming sector, and by 60 percent in industrial processes from its 2015 levels.[8] The key measures to be employed as part of its strategy are as follows:

- Deployment of energy efficiency measures across all applicable sectors.
- Prompt behavioral changes to aid citizens to adopt a climate-sustainable lifestyle and promote products from the bio-economy.
- Safeguard carbon sinks such as soils and forests.
- Promote and deploy Carbon Capture and Storage (CCS) technology.
- Mainstreaming sustainable development issues as an essential clause in future trade agreements.
- Adopt the Carbon Border Adjustment Mechanism (CBAM) proposed in the EU.

France's electricity transmission system operator (RTE) estimates that by 2050, the final electricity consumption across sectors will be between 700–755TWh[9], assuming a rapid electrification scenario where end-users, typically in the transport and heating sector, largely transition to electricity. A fully renewable energy source scenario estimates the installed capacity requirement by 2050 to be 344 GW[10]. Additionally, the French Government has set a low-carbon hydrogen production target of 0.4 Mt/year by 2028 and seeks to develop 6.5GW of green hydrogen electrolysis production capacity by 2030. Around €7.2bn has been earmarked up to 2030 to strengthen France's green hydrogen production[11].

CASE STUDY

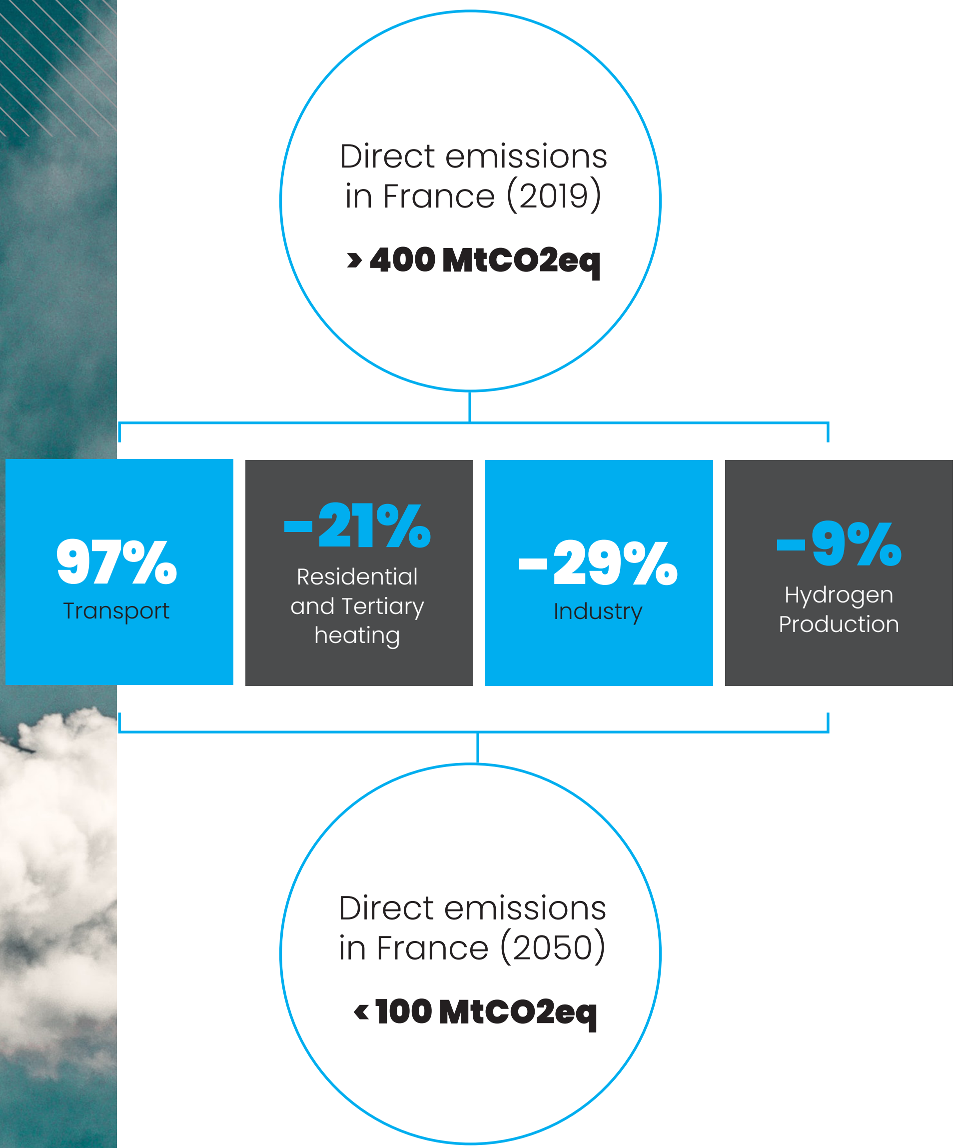
Reducing GHG Emissions in France by Electrification

Energy pathways developed for France profess that the strongest climate impact can be achieved by replacing fossil energy with electricity (or hydrogen produced from electricity) in passenger and freight road transport. The replacement of fuel oil and fossil gas heating systems during building renovation, and greater use of electricity or low-carbon hydrogen for certain industrial processes, or electric boilers, are other ways to reduce emissions[7]. Among the end-uses, the transformation will be significantly observed in sectors where electricity is not a mainstream source of energy today. By 2050, it is estimated that electricity demand in the transport sector could reach 100TWh as opposed to 15 TWh today, and a similar spike is estimated for the industry sector. Hydrogen production is also estimated to require 50 TWh in 2050 as opposed to zero today.

On the path to offsetting direct emissions, Figure 1 represents the contribution of electrification strategies in reducing direct emissions by 2050. Sector-wise percentage decrease in emissions resulting directly from electrification is observed and the importance of electrification in the transport and industry sector is reiterated.

7 See: https://assets.rte-france.com/prod/public/2022-01/Energy%20pathways%202050_Key%20results.pdf.
8 See: https://sdg.iisd.org/news/france-switzerland-present-roadmaps-to-reach-net-zero-by-2050/.
9 See: https://assets.rte-france.com/prod/public/2022-01/Energy%20pathways%202050_Key%20results.pdf. .
10 See: https://assets.rte-france.com/prod/public/2022-01/Energy%20pathways%202050_Key%20results.pdf.
11 See: https://www.rvo.nl/sites/default/files/2022/01/Hydrogen-sector-study-France-maart-2021.pdf.

Figure 1: Contribution of electrification in emission reduction of key sectors in France



2.1.3. GERMANY

Strategy to Net-Zero

Germany has set a target to become climate-neutral by 2045. A climate law adopted in 2021 revised its target to reduce emissions by 60 percent[12] compared to 1990 levels, which is much higher compared to the country's original commitment as part of the European Union's (EU) 'Fit for 55' plan. Additionally, a new interim target was set to reduce emission levels by 88 percent[13] compared to 1990 levels. As part of its strategy to attain climate neutrality by 2045, Germany intends to adopt the following measures:[14]

12 See: https://climateactiontracker.org/countries/germany/targets/.
13 See: https://climateactiontracker.org/countries/germany/targets/.
14 See: https://www.mckinsey.com/business-functions/sustainability/our-insights/net-zero-germany-chances-and-challenges-on-the-path-to-climate-neutrality-by-2045.

- Accelerate expansion of renewable energy to result in a threefold increase, while also expanding the energy grid (~25 percent) and increasing its flexibility.
- Decarbonise the basic-materials industry by driving innovation in production technologies. Specific emphasis on hydrogen production and transportation, charging infrastructure and carbon capture systems.
- Introduce sustainable heating systems such as heat pumps (over 50 percent penetration) in buildings.
- Promote consumer behavior that leads to sustainable consumption and develop technologies to enable a resilient and climate-compatible agriculture sector.
- Develop a green portfolio to support financial requirements of the net-zero transformation.

Germany has also set a target to achieve 14TWh[15] of green hydrogen capacity by 2030.

CASE STUDY

Electrifying Key Sectors in Germany[16]

In a study of Germany's pathway to net-zero through electrification, it shows that the country has adopted different decarbonisation strategies customised to each sector. The Best Available Technology (BAT) is assumed to be employed in the sector and innovations that have demonstrated their feasibility, at least through a pilot, have been considered for the electrification scenario. To illustrate this, the assumptions for electrification-specific processes across the value-chain in the iron and steel, and chemical sectors have been shown in Table 2.

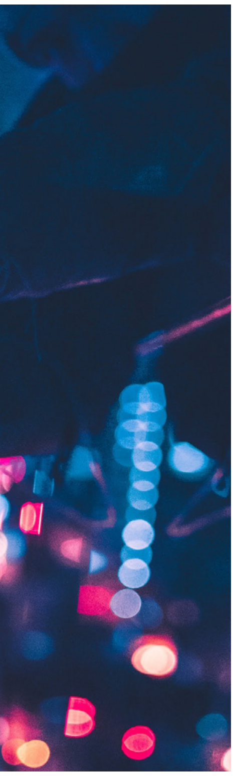
Table 2: Value chain assumptions for electrification scenario

Sector	Energy and Process Efficiency	Energy Carrier and Process Switch	Recycling and Circular Economy	Material Efficiency and Substitution
Iron and Steel	BAT, thin slab or strip casting	H2-DRI, plasma steel	Electric steel share (scrap-based) increases from 30 to 60 percent	Efficient steel use Substitution
Chemicals	BAT, oxygen depolarised cathode, selective membranes	Electric boiler, H2 for olefines, methanol, ammonia, some biomass for feedstocks	Increased recycling of plastics reduces primary use by 30 percent	Reduction and substitution of plastic consumption, and reduction of ammonia use in fertilizers

In heat generation applications across various processes, direct electrification is employed to a large extent. Large industrial heat pumps are used, provided the temperature levels are within operational levels. Furnaces and boilers have already been replaced by direct electrification technologies. In steel production and certain processes in the chemical industry, hydrogen produced by means of water electrolysis using renewable electricity is employed. Progress in material efficiency is assumed in all industries and strategies in the direction of a circular economy are made at product level.

Result: In this scenario, **93 percent GHG reduction can be achieved by 2050 compared to 1990 levels.** The remaining GHG emissions are pointed to be coming exclusively from processes and minimal remaining quantities of fossil fuels. The scenario achieves a total reduction of 56 percent in direct emissions, thereby exceeding the target set for German industry of reduction between 49 to 51 percent.

15 See: https://energypost.eu/germanys-plans-to-be-a-hydrogen-leader-producer-consumer-solutions-provider/.
16 See: https://www.eceee.org/library/conference_proceedings/eceee_Industrial_Summer_Study/2020/6-deep-decarbonisation-of-industry/deep-decarbonisation-of-the-german-industry-via-electricity-or-gas-a-scenario-based-comparison-of-pathways/.



2.2. MULTI-CRITERIA DECISION MATRIX (MCDM) APPROACHES

To select the optimal solution among the options requires formulation of decision-making strategies with scientific backing. This includes ranking a set of interventions that belong to the same real-world set where the choice of 'best' among the 'better' options is tricky to identify, and requires some insight. MCDM's versatility can be manifested from the fact that it can be applied in all areas of decision theory such as management, manufacturing, transport, education, agriculture, and more. Hence, it is widely used by policymakers, researchers, and other professionals across domains in interactive decision-making and in a decision support system. The first usage of MCDM was found in research pieces written more than six decades ago. Since then, myriad work pieces have incorporated and benefitted from MCDM. Moreover, there are numerous review papers on MCDM that examine their assumptions, strengths, and limitations to identify the right approach for the select application[17,18,19].

To date, MCDM remains an important area of research, and information on more than 70 different MCDM approaches is available in the public domain. These MCDM approaches employ a few key generic steps that are highlighted in Figure 2[20]. The first step is the identification of the interventions that need to be ranked followed by elucidation of the criteria for ranking. These criteria may be a conjunction of qualitative and quantitative parameters. The next step involves assigning the preferences to the evaluation criteria which can be done based on various techniques depicted in Figure 3. The fourth step is choosing the right MCDM approach for the application, followed by the evaluation of the performance score. Finally, the ranking is done based on the performance scores and the results are furnished for the users.

Figure 2: Generic Steps of MCDM Approaches

17 Jayanth Ananda, et.al., *A critical review of multi-criteria decision making methods with special reference to forest management and planning*.
18 Smith, P.G.R., Theberge, J.B., 1986. *A review of criteria for evaluating natural areas. Environmental Management 10*, 715–734.
19 Stewart,T.J., 1992. *A critical survey on the status of multiple criteria decision-making theory and practice*. OMEGA International. Journal of Management Science 20, 569–586.
20 Aarushi Singh, et.al, *Major MCDM Techniques and their applications- A Review*.

Figure 3: Arriving at Weights for Prioritizing Evaluation Criteria[21]

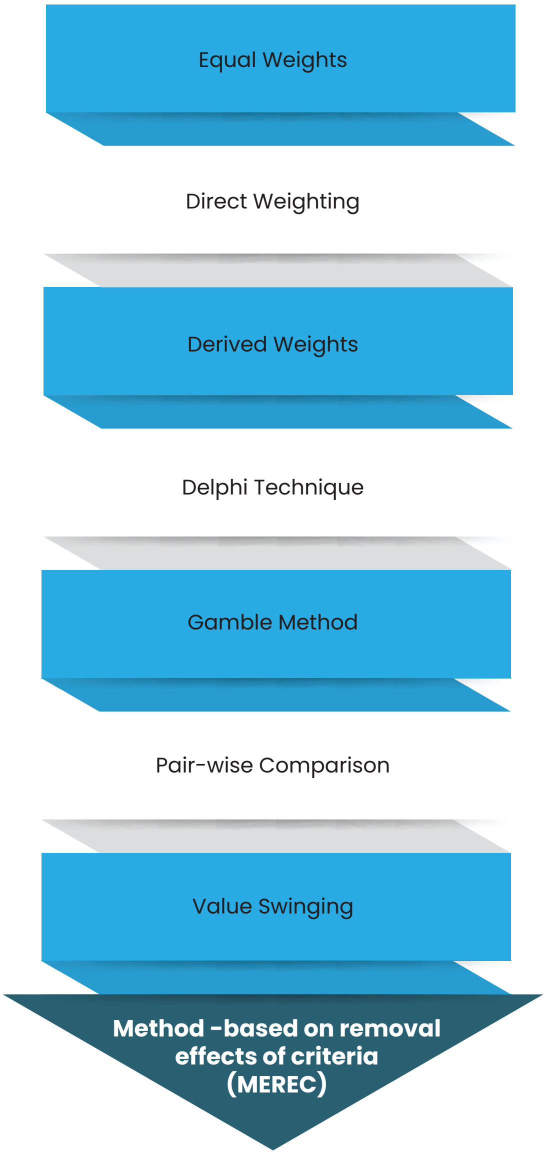


Table 3 represents a template of the final decision matrix based on **n** interventions and **m** criterion. Here, a_{nm} represents the performance score of n^{th} intervention against m^{th} criterion.[22] A holistic review of about 18 MCDM approaches led to the conclusion that the calculation of the performance score is the key differentiating element (Step 5).

Table 3: Final Decision Matrix Template

	Criteria 1	Criteria 2	......	Criteria m
Intervention 1	a_{11}	a_{12}		a_{1m}
Intervention 2	a_{21}	a_{22}		a_{2m}
.....				
Intervention n	a_{n1}	a_{n2}		a_{nm}

Another key facet that was unfurled during the literature review was the presence of around five key MCDM approaches that dominated the research in the last five years. Table 4 captures details on those approaches. Also, no approach was exclusively used for a particular application. Most researchers selected two or more MCDM approaches and used one of them for ranking the interventions and the remaining to validate the results obtained from the first approach. This allowed the researchers to overcome the limitations of individual approaches. Also, this allows circumventing the consequences of mismatches that may lead to suboptimal results.

21 See: https://www.researchgate.net/publication/335806989_Weighting_methods_for_multi-criteria_decision_making_technique. Accessed on ___.

22 Valerio A.P. Salomon, et. al, *A compilation of comparisons on the analytic hierarchy process and others multiple criteria decision making methods: Some Cases Developed in Brazil.*

Table 4: Details on Key MCDM Approaches[23,24]

Sr. No.	MCDM Approach	Origin	Description
1	Weighted Sum Model (WSM)	NA	This model is also termed Weighted Linear Combination (WLC). In this model, the weights of the criteria are multiplied by normalised intervention values to arrive at the performance score. Each criterion is given weights depending on their severity while ensuring that the sum of each weight is 1. This performance score is then summed up and the interventions are sorted to arrive at the top interventions.
2	Techniques for Order Preferences by Similarity to Ideal Solutions (TOPSIS)	Hwang and Yoon in 1981	This approach is based on distance matrices. Here, the Euclidean distance is used for ranking interventions from ideal positive and ideal negative solutions. This approach selects the alternative whose value is closest to the positive ideal solution and farthest from the negative ideal solution.
3	Analytic Hierarchy Process (AHP)	Thomas L. Saaty in 1970	This approach aggregates separate criteria into a unified criterion. Here, the preferences of the decision elements use a hierarchical structure and pairwise comparison of each intervention by assigning relative importance. If two criteria are of equal importance, a value of 1 is assigned to both. On the flip side, a value of 9 manifests the importance of the criteria over all others.
4	Elimination Et Choice Translating Reality (ELECTRE)	1968	This is an outranking model that uses pairwise comparison by using concordance and discordance indexes. Here, the concordance index expresses the fuzzy membership value of the intervention, and the discordance index measures the comparability of interventions.
5	Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE)	Jean-Pierre Barns and Bertrand Mareschal in 1983	Another outranking model tries to outrank one alternative by the other concerning a preference function and a net outranking flow. It allows the decision-maker to partially or completely rank the interventions by defining a preference function for each criterion.

23 Jayanth Anand, et.al, *A critical review of multi-criteria decision making methods with special reference to forest management and planning.*
24 Aarushi Singh, et. Al, *Major MCDM Techniques and their application- A Review.*

3. Mapping of Sectors and Sub-Sectors

A deep electrification study would be remiss without ensuring an economy-wide account of sectors and their associated emission-intensive activities. This step was necessary to identify the priority sectors for deep electrification, that would enable the attainment of India's net-zero goals. Various factors were probed to ascertain the top sectors that were emission-intensive and impacting the economy. Six parameters were determined to attribute the environmental impact of sub-sectors identified from the GHG India Platform and data was collated for the same as described in Table 5.

Table 5: Description of Sectoral Data Collected

Data	Source	Derived Parameters	Year
Emissions	GHG India Platform	1. Percentage of emission share 2. Rate of change in emissions	2011 to 2018
Fossil Fuel Usage	India Energy Dash-board, NITI Aayog	3. Fossil fuel solid usage in TJ (Coal) 4. Fossil fuel liquid and Gas in TJ (Oil and Gas) 5. Rate of Change in fossil fuel usage	2011 to 2018
Gross Value Added (GVA)	RBI; Annual Survey of Industries (2018-19)	6. GVA considered in crore rupees	FY 2018-19

Various factors were probed to ascertain the top sectors that were emission-intensive and impacting the economy

While emissions were available exhaustively for 85 sub-sectors from the GHG India platform, data for sectoral fossil fuel usage and associated GVA, were available for grouped sub-sets only. To normalise the data collection process, the common reporting format for sector classification provided by the Intergovernmental Panel on Climate Change (IPCC), was referred to club the sub-sectors and arrive at common sub-sectors corresponding to data availability.

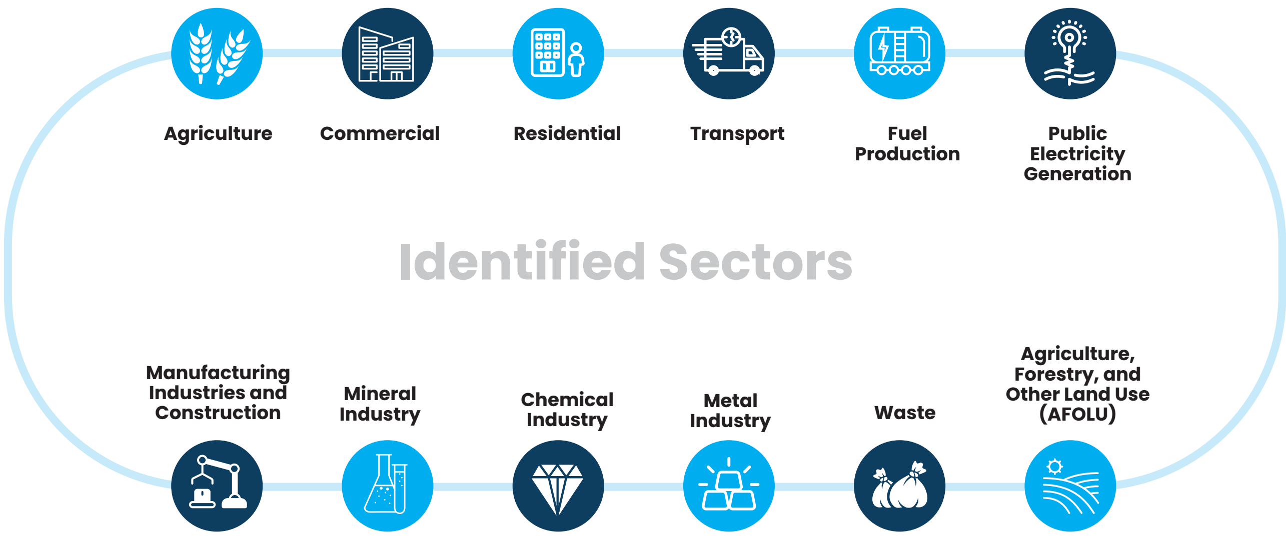
The fossil fuel usage was collected based on the broad classification of Coal, Oil, and Gas consumption in each sector. The data obtained were in different unit measures and hence the energy usage for each sector and from each fuel type was determined as a common factor. Certain assumptions were made about obtaining the respective calorific values for the conversion, as described in Table 6.

Table 6: Description of Calorific Values Assumed for Energy Conversion

Calorific Value				
Fuel Source	**Value**	**Unit**	**Description**	**Reference**
Coal[25]	4600	kcal/kg	Average of existing 17 grades of coal as specified in the ministry of coal website	Coal Grades (Ministry of Coal)
Oil pro-duct[26],[27]	10,693	kcal/kg	Aviation fuel – 10397; Petrol – 10755; Kerosene - 11100 Diesel Oil - 10,800 L.D.O - 10,700 Furnace Oil - 10,500 LSHS - 10,600 (**Average calorific value of above fuels is considered**)	Bureau of Energy Efficiency (BEE)
Gas[28]	9000	kcal/m3	Natural gas in India has a calorific range from 8000 kcal/m3 to 9480 kcal/m3. Assumption made in accordance with TERI study.	The Energy and Resources Institute (TERI)

The exercise resulted in 12 key sectors that represented the Indian economy as a whole, where the emissions, fossil fuel consumption, and GVA equaled their national sum respectively. Figure 4 represents the final sector list that has been carried forward in this study.

Figure 4: Final List of Sectors



25 See: https://coal.gov.in/en/major-statistics/coal-grades. Accessed on ___.
26 See: https://beeindia.gov.in/sites/default/files/2Ch1.pdf. Accessed on ___.
27 See: https://www.intechopen.com/chapters/69326. Accessed on ___.
28 See: https://bookstore.teri.res.in/docs/books/TEDDY14/indianenergy/commercial%20energy.pdf. Accessed on ___.

4. Framework for Ranking Sectors

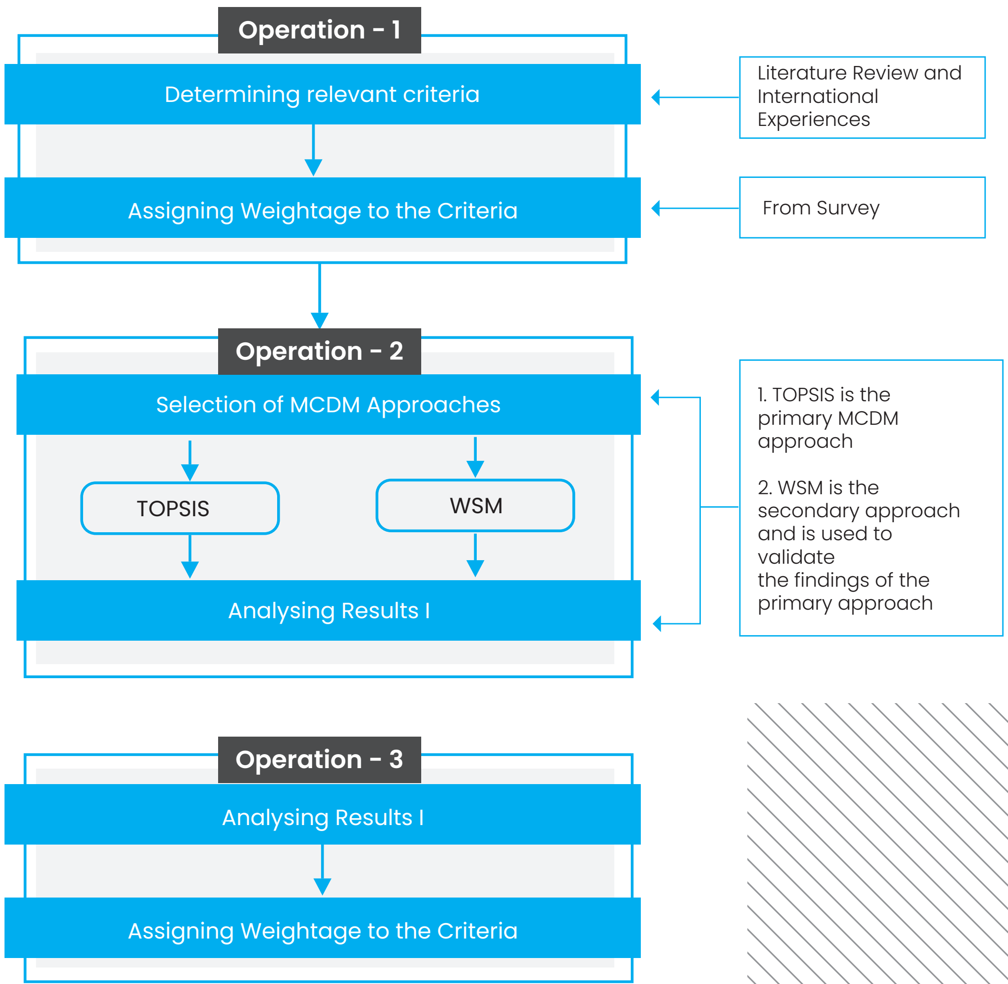
Selection of sectors to prioritise for deep electrification is a complex exercise as the resources have competing uses and the stakeholders are heterogeneous. Thus, this exercise requires MCDM approaches to examine the tradeoffs, and consider environmental and economic dimensions via an optimising framework. This section captures the sequence of operations carried out to rank the sectors accordingly. These operations are visually captured in Figure 5.

Operation 1 **Determining relevant criteria and their associated weights-** Criteria for ranking the sectors, along with weights, has been discussed in section 4.1.

Operation 2 **Carrying out numerical analysis based on the selected MCDM approach**- For this paper, we have selected Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) as the primary MCDM approach and validation will be carried out using the WSM approach.

Operation 3 **Perform convergence of the selected MCDM approaches and rank the sectors**- Final ranking of the interventions will be carried out by summing the performance values deduced from MCDM approaches mentioned in operation 2.

Figure 5: **Framework for Ranking the Sectors**



4.1. IDENTIFICATION OF EVALUATION CRITERIA AND THEIR CORRESPONDING WEIGHTS

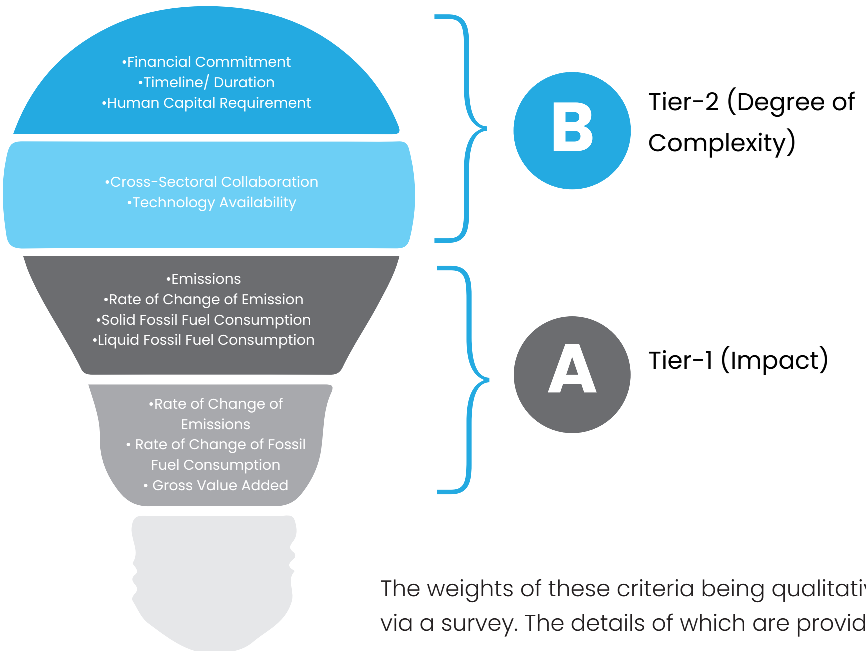
For optimising the process of choice, there is a need to differentiate the interventions and arrive at a ranking. These can be a combination of qualitative and quantitative factors that are collectively known as criteria. The proper determination of the applicable evaluation criteria is important because they have great influence on the outcome. On the other hand, using all the criterion in the selection process is not the best approach as criterion can represent the same facet such as trend, idea, and more.

We have employed a two-tier approach to identify the criteria as seen in Figure 6. The **first tier** is quantitative and focuses on the **impact** of each parameter of the sectors. This impact can be measured in specific buckets such as Emissions Released, Solid and Liquid Fossil Fuels Consumed, Economic Impact in Gross Value Added (GVA), and Ecological Impact (Air Pollution, Usage of Hazardous Materials). Another key aspect to measure impact is the rate of change of emissions, and rate of change of solid and liquid fossil fuels consumption. However, in our final analysis, we have not included ecological impact due to the paucity of sectoral data in the public domain.

The **second-tier** criteria are qualitative and are based on the **degree of complexity** associated with the deep electrification of the sectors. Here, factors such as financial commitment, and technology availability have been deemed as parameters to assess the extent of support required by each sector for deep electrification. The definitions of the qualitative parameters under this approach are as follows:

1. **Financial Commitment:** Refers to expected/ predicted financial requirements for decarbonising the sector.
2. **Timeline/Duration**: Refers to the expected duration of expediting decarbonisation measures.
3. **Human Capital Requirement**: Refers to the expected need for competent human resources with desired skill sets.
4. **Cross-Sectoral Collaboration:** Refers to the expected degree of collaboration required across sectors to expedite decarbonisation measures.
5. **Technology Availability**: Refers to the extent of technology currently available in the research and development, deployment, and commercialisation stage.

Figure 6: Tier- 1 and 2 Evaluation Criteria



The weights of these criteria being qualitative in nature were derived via a survey. The details of which are provided in Section 5.

5. Survey for Qualitative Parameters

The survey was developed to receive inputs for the qualitative criteria and to determine the weights to be attached to the criterion. The first part of the survey sought to allot priority on a linear scale to gauge the perceived importance of each criterion as shown in Figure 6. Based on the responses, percentage weights were allotted to the criterion from both the tiers, respectively.

Figure 7: Survey Snapshot Determining Percentage Weights for Tier-1 Criteria

Ranking for Tier-1 criteria*

	1	2	3	4	5
1. Emissions: Refers to the annual emissions from each sector.	○	○	○	○	○
2. Rate of increase of emissions: Refers to CAGR of emissions from each sector over a common time period.	○	○	○	○	○
3. Fossil fuel usage (Solid): Refers to the Quantum of annual Coal consumption in each sector.	○	○	○	○	○
4. Fossil fuel usage (Liquid and Gas): Refers to the Quantum of annual Oil and Gas consumption in each sector.	○	○	○	○	○
5. Rate of increase of fossil fuel usage: Refers to the CAGR of sector-wise annual fossil fuel consumption over a common time period.	○	○	○	○	○
6. Gross Value Added (GVA): Refers to the GVA attributed to the particular sector.	○	○	○	○	○

In the second part of the survey, qualitative inputs towards each sector were arrived at by seeking responses (low, medium, and high) that referred to the level of importance they attributed to the specific criteria in the respective sector. The results for Tier-2 criteria were interpreted using a desirability matrix as illustrated in Table 8.

Table 7: Desirability Matrix for Tier-2 Criteria

	Least desirable	Medium desirable	Most desirable
Financial Commitment	Low	Medium	High
Timeline/Duration	High	Medium	Low
Human Capital Requirement	High	Medium	Low
Cross-Sectoral Collaboration	High	Medium	Low
Technology Availability	Low	Medium	High

Each of the Criteria was assigned a level of importance that reflected its desirability as shown in Figure 7. For example, if a respondent allotted **high** importance to 'human capital requirement', it was interpreted as the *least desirable* outcome. The rationale for the decided desirability reflects that the deep electrification processes can be served by repurposing the existing workforce, rather than undertaking skill development and training exercises afresh. Similarly, a response of **low** importance for 'Technology availability' is interpreted as the *least desirable* outcome. The rationale for this decided desirability is that technology is critical for direct or indirect electrification of existing sectoral processes and warrants priority.

Figure 8: Survey Snapshot of Sector-Wise Assessment

Agriculture *

Agriculture sector is categorized into stationary combustion of diesel for pumping, and mobile combustion of diesel in farm mechanization.

	Low	Medium	High
Financial Commitment	○	○	○
Timeline/ Ouration	○	○	○
Human Capital Require ...	○	○	○
Cross-sectoral Collabor ...	○	○	○
Technology availability	○	○	○

The survey posed this exercise for each of the identified sectors and points were allotted to arrive at a normalised score. In each sector, for *least desirable* response, a score of **1** was allotted. Similarly, the *most desirable* response was allotted a score of **3**, with the *medium desirable* response garnering a score of **2**. The points scored across the tier-2 criterion were summed for each sector and were used in the MCDM approaches as mentioned in the previous section.

5.1. SURVEY MODALITIES

Sample size determination is an important step in the design of a research study. This provides confidence to the researcher that the facts inferred from the sample are representative of the population. Common sampling methods include purely random sampling, cluster sampling, systematic sampling, among others. Moreover, it is important to highlight that specific surveys around technical ideas require some basic level of understanding of modalities. Thus, the sample size is usually less than the consumer surveys, in general.[29]

For this survey, we consider the participation of stakeholders across the value chain. These include policymakers, industry partners, academia, civil society organisations, etc. The population size will be the summation of the people working in the aforementioned fields and are at the helm of decision making. A back-of-the-envelope calculation culls out 1 million as the population size.

Now, for confidence level of 90 percent (z-score = 1.65) and margin of error (e) of 7percent {usually between 5-10 percent}, the sample size is,

$$\text{Sample Size} = \frac{\frac{z^2 P(1-P)}{e^2}}{1 + \frac{z^2(1-P)P}{e^2 N}}$$

Sample size = 139

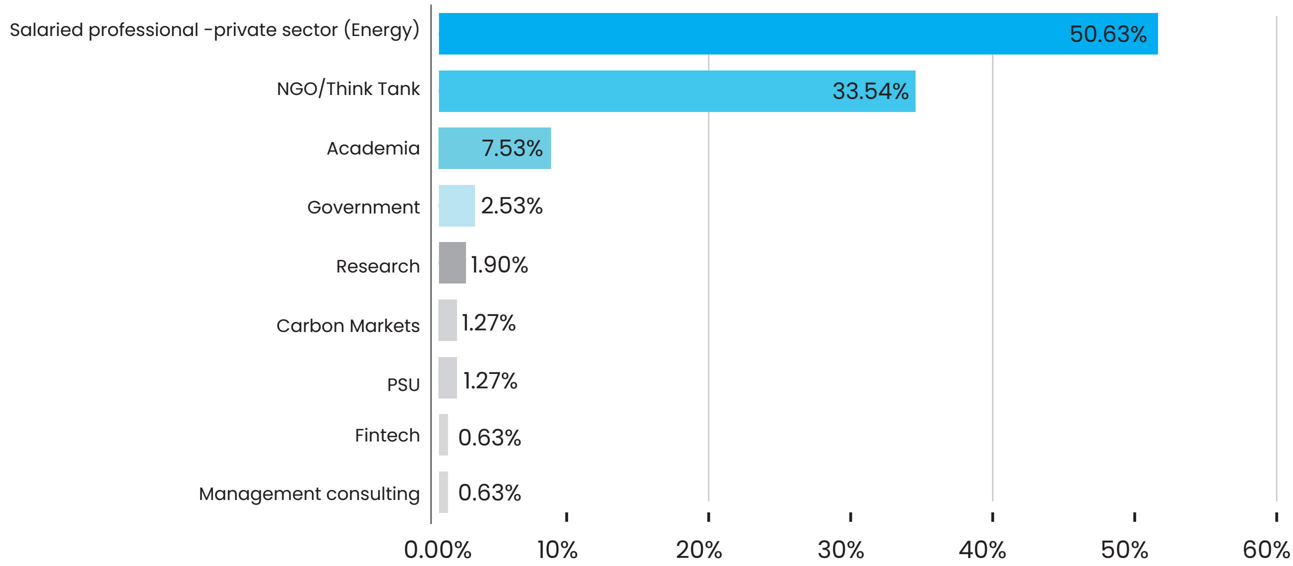
Hence, using a google form, we surveyed around 158 individuals across 66 institutions. This survey methodology can be extended to a larger population size in the future when the discourse around deep electrification picks up.

29 See: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3409926/. Accessed on __:

6. Analysis

The responses gathered from the survey were instrumental in defining the parameters for ranking the sectors. Deep electrification perspectives were received from a wide mix of professionals as shown in Figure 8. Majority of the responders were Energy professionals in the private sector, followed by professionals from think tanks in the Energy domain.

Figure 9: Description of Sector of Work of Survey Respondents



The results of this survey were used to carry out the MCDM exercise and arrive at a ranking for the identified sectors.

6.1. PERCENTAGE WEIGHTS ATTRIBUTED TO CRITERIA

The survey comprised two critical sections to enable the attribution of percentage weights to Tier-1 and Tier-2 criteria, and also to gather qualitative perspectives on deep electrification for each of the identified sectors as part of this study. In the first section, respondents provided their inputs on a scale of 1 to 5 in ascending order of importance attributed to the corresponding parameter part of the respective tier. The average of the responses was calculated to determine the final importance to be attached to each of the parameters from Tier-1 and Tier-2. The results are shown in Table 9.

Table 8: Average Scores Derived for Tier-1 and Tier-2 Criteria

Average score	1	2	3	4	5
Tier-1 Criteria	-	-	• Gross Value Added (GVA)	• Rate of Increase of Emissions • Fossil Fuel Usage (Solid) • Rate of Increase of Fossil Fuel Usage	• Emissions • Fossil Fuel Usage (Liquid and Gas)
Tier-2 Criteria	-	-	• Cross-sectoral Collaboration	• Timeline/Duration • Human Capital Requirement	• Financial Commitment • Technology Availability

It is observed that Emissions and Fossil Fuel Usage (Liquid and Gas), are deemed to be the most important among the Tier-1 criteria. Similarly, Financial Commitment and Technology Availability are deemed to be the most important among the Tier-2 criteria. The other parameters received corresponding average scores as observed in Table 9. Based on the inputs received, percentage weights were attributed to the parameters from both criteria as shown in Table 10.

Table 9: Percentage Weights Attributed to Tier-1 and Tier-2 Criteria

Tier-1					
Emissions	Rate of Increase of Emissions	Fossil Fuel Usage (Solid)	Fossil Fuel Usage (Liquid and Gas)	Rate of Increase of Fossil Fuel Usage	Gross Value Added (GVA)
25%	15%	15%	25%	15%	5%

Tier-2				
Financial Commitment	Timeline/ Duration	Human Capital Requirement	Cross-Sectoral Collaboration	Technology Availability
30%	15%	15%	10%	30%

6.2. QUALITATIVE INPUTS ON DEEP ELECTRIFICATION OF IDENTIFIED SECTORS

The importance attached (low, medium, and high) to each of the Tier-2 criteria was sought sector-wise. As explained in the previous section (refer section 5), the responses from the survey were allotted scores by referring to Table 8. The average of these scores was obtained to derive the final importance to be attached to each parameter, sector-wise, as seen in Table 11.

Table 10: Final Tier-2 Attributes for the Identified Sectors

List of Sectors	Financial Commitment	Timeline/ Duration	Human Capital Requirement	Cross-Sectoral Collaboration	Technology Availability
Agriculture	High	High	High	Medium	Medium
Commercial	Medium	High	Medium	Low	Medium
Residential	Medium	High	High	Medium	Low
Transport	High	High	High	High	High
Fuel Production	Medium	Medium	High	Low	Medium
Public Electricity Generation	Medium	Medium	Medium	Medium	Medium
Manufacturing Industries and Construction	Medium	Medium	High	Low	Medium
Mineral Industry	Low	Medium	Medium	Low	Low
Chemical Industry	Medium	High	Medium	Medium	Medium
Metal Industry	Medium	High	Medium	Medium	Medium
Waste	Medium	Medium	Medium	Low	Low
AFOLU	Low	Medium	Medium	Low	Low

6.3. MCDM EXERCISE

After obtaining the required inputs from the survey, the MCDM exercise was expedited by using TOPSIS as the primary MCDM approach, followed by WSM as the secondary approach for validating the former. Normalised matrices were obtained for both the tiers and using the percentage weights resulting from the survey, weighted normalised scores were derived as shown in Annexure. The performance scores shown in Table 12 were arrived at by progressing through the various steps of TOPSIS and WSM methods. The table also showcases the convergence of performance scores from TOPSIS against WSM. Four out of top five sectors of TOPSIS method also appear in top 5 list of WSM method (80 percent convergence).

Table 11: Performance Scores Derived for Identified Sectors

	Performance score (TOPSIS)	Performance score (WSM)
Agriculture	0.989	0.481
Commercial	0.967	0.570
Residential	0.566	0.313
Transport	1.181	0.597
Fuel Production	0.800	0.358
Public Electricity Generation	1.189	0.795
Manufacturing Industries and Construction	0.960	0.568
Mineral Industry	0.515	0.276
Chemical Industry	0.806	0.398
Metal Industry	0.755	0.299
Waste	0.618	0.324
AFOLU	0.480	0.282

7. Final Result

The performance scores obtained for the two MCDM approaches were combined to arrive at a final performance score. The sectors were then ranked based on cumulative performance score achieved by the respective sector. Table 13 shows the final ranking of sectors that highlight the urgency and potential for the implementation of deep electrification strategies.

Table 12: Final Ranking of Identified Sectors

Final List of Sectors	Ranking
Public Electricity Generation	1
Transport	2
Commercial	3
Manufacturing Industries and Construction	4
Agriculture	5
Chemical Industry	6
Fuel Production	7
Metal Industry	8
Waste	9
Residential	10
Mineral Industry	11
AFOLU	12

Annexure

1. WEIGHTED NORMALISED MATRIX OF TIER-1 CRITERIA

Percentage weight	25%	15%	15%	25%	15%	5%
Final List of Sectors	Emissions (2018)	Rate of Increase of Emissions (CAGR 2011 - 2018)	Fossil Fuel Consumption (Solid)	Fossil Fuel Consumption (Liquid and Gas)	Rate of Use of Energy (2011 - 2018 CAGR)	Gross Value Added (in crore rupees;2018-19)
Agriculture	0.008	0.036	0.000	0.096	0.046	0.000
Commercial	0.002	0.044	0.000	0.174	0.039	0.020
Residential	0.025	0.014	0.000	0.055	0.012	0.000
Transport	0.057	0.057	0.000	0.096	0.046	0.011
Fuel Production	0.008	-0.052	0.000	0.063	0.046	0.001
Public Electricity Generation	0.216	0.063	0.150	0.025	0.031	0.003
Manufacturing Industries and Construction	0.086	0.010	0.001	0.059	0.081	0.037
Mineral Industry	0.026	0.054	0.002	0.003	-0.042	0.004
Chemical Industry	0.009	0.011	0.000	0.055	0.040	0.002
Metal Industry	0.004	0.066	0.004	0.002	-0.059	0.002
Waste	0.022	0.030	0.000	0.000	0.000	0.000
AFOLU	0.055	-0.027	0.000	0.000	0.000	0.023

2. WEIGHTED NORMALISED MATRIX FOR TIER-2 CRITERIA

Percentage weight	30%	15%	15%	10%	30%
Final List of Sectors	Financial Commitment	Timeline/ Duration	Human Capital Requirement	Cross-Sectoral Collaboration	Technology Availability
Agriculture	0.125	0.027	0.026	0.023	0.094
Commercial	0.083	0.027	0.052	0.035	0.094
Residential	0.083	0.027	0.026	0.023	0.047
Transport	0.125	0.027	0.026	0.012	0.141
Fuel Production	0.083	0.055	0.026	0.035	0.094
Public Electricity Generation	0.083	0.055	0.052	0.023	0.094
Manufacturing Industries and Construction	0.083	0.055	0.026	0.035	0.094
Mineral Industry	0.042	0.055	0.052	0.035	0.047
Chemical Industry	0.083	0.027	0.052	0.023	0.094
Metal Industry	0.083	0.027	0.052	0.023	0.094
Waste	0.083	0.055	0.052	0.035	0.047
AFOLU	0.042	0.055	0.052	0.035	0.047

3. SECTOR-WISE APPLICATIONS TO BE ELECTRIFIED

Agriculture	Commercial	Residential	Transport	Fuel Production	Public Electricity Generation	Manufacturing Industries and Construction	Mineral Industry	Chemical Industry	Metal Industry	Waste	AFOLU
DG Pumpsets	DG Gensets	DG Gensets	2-wheeler	Pumps	DGSets	Furnace	Furnace	Boiler	Furnace	DG Pumpsets	DG Pumpsets
Power harrow	DG Pumpsets	DG Pumpsets	3-wheeler	Coolers	DG Pumpsets	Rollers	Rollers	Grinders	Rollers	DG Gensets	DG Gensets
Rotavator	Tandoor Oven	Tandoor Oven	Cars	Condensers		Rotary kiln	Rotary kiln	Heaters	Rotary kiln	Shredder	
leveller	Cookstoves (gas-based, kerosene, firewood and coal)	Cookstoves (gas-based, kerosene, firewood and coal)	Mini Trucks	Compressors		Crusher	Crusher	Mixers	Crusher	Press	
Ripper machine	Waterheater (gas-based)	Waterheater (gas-based)	Trucks	Drill machines		Heaters	Heaters	Strip processing	Heaters		
Combine harvester	Spaceheaters (gas-basedand wood-based)	Spaceheaters (gas-basedand wood-based)	Buses	Continuous miner		Mixers	Mixers	Debarking drum	Mixers		
Cultivator	Coal-basedironbox	Coal-basedironbox	Aircraft	Pulverisier		Strip processing	Strip processing	Chipper	Strip processing		
Seeder/Planter	Non-electricbody cremators		Ships	Shredder		Debarking drum	Debarking drum	Refiner	Debarking drum		
Thresher			Ferry	Wheeldozer		Chipper	Chipper	DGSets	Chipper		
Aeraon devices			Boats	Dump Truck		Refiner	Refiner	DG Pumpsets	Refiner		
Tractor Trailer			Railways	Feeder breaker		DGSets	DGSets	Gas-Welding	DGSets		
Refrigerated Trucks				Excavator		DG Pumpsets	DG Pumpsets	Compressors	DG Pumpsets		
				Roofbolter		Gas-Welding	Gas-Welding		Gas-Welding		
				DGsets		Compressors	Compressors		Compressors		
				Dryer							
				Drill Press							
				Mixer							

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